"NOT TOO OLD" METAL DEFICIENT STELLAR POPULATIONS: THE CASE OF METALLICITY Z=0.00001.

S. Cassisi[1,2], M. Castellani[3] and V. Castellani[1,4]

[1] *Osservatorio Astronomico Collurania,Via Mentore Maggini,I-64100 Teramo, Italy*
[2] *Universitá de l'Aquila, Dipartimento di Fisica, Via Vetoio,I-67010 L'Aquila, Italy*
[3] *Universitá "La Sapienza", Istituto Astronomico, Via Lancisi 29,I-00161 Roma, Italy*
[4] *Universitá di Pisa, Dipartimento di Fisica, Piazza Torricelli 2,I-56100 Pisa, Italy*

Abstract. We investigate the evolution of metal deficient stellar structures, presenting H-burning isochrones covering cluster ages from 800 Myr to 7 Gyr. Evolutionary evidences for selection effects in the metallicity distribution of very metal poor H-burning red giants are reported. The evolution of stars during central and shell He burning is further investigated, discussing the occurrence of He burning pulsators as a function of cluster age.

1. Introduction

Since the pioneering work by Bond (1970), in the past few decades much observational effort has been devoted to searching for very metal poor stars. As a consequence, one is dealing with an increasing evidence for metal deficient stars membering the Galactic Halo (see, e.g., Molaro & Castelli 1990, Primas et al. 1994, Sneden et al. 1994), renewing the interest in theoretical constraints concerning the evolution of similar very metal poor objects. As matter of fact, even if the approach to the evolution of metal deficient stars dates to the early seventies, this argument is still open to investigation. In a preliminary paper Cassisi & Castellani (1993) presented a rather extensive investigation of the theoretical scenario concerning these peculiar stellar objects. However, their analysis was mainly devoted to the study of the 'Red Giant Phase Transition' (see below) in low mass stars as well as to the determination of the lower mass limit (M^{up}) for quiet carbon ignition in more massive stars. This scenario has been recently improved by Cassisi et al. (1995; Paper I) who investigated H and He burning phases for low mass, metal deficient stars, presenting theoretical isochrones for ages in the range 7 - 15 billion of years and discussing the evolutionary expectations for RR-Lyrae stars.

According to these results, one finds that old Population III and Population II stars have been rather extensively investigated in the literature. However, the

evidence is increasing for dwarfs spheroidals being metal poor systems, but 'not too old', i.e., not as old as galactic globular clusters are. Such an evidence has recently suggested the opportunity to extend to larger masses evolutionary computations concerning metal poor stellar structures. Accordingly, Castellani & Degl'Innocenti (1995) have discussed the evolutionary behavior of stars up to about $2M_{\odot}$, for the two selected choices on the amount of heavy elements: $Z = 10^{-4} - 4 \cdot 10^{-4}$, extending in such a way previous investigations of metal poor stars to cluster ages lower than 1 Gyr. However, suggestions have been advanced for the occurrence in dwarf spheroidal of a not negligible spread of metallicities, with the possible occurrence of stars with even lower values of Z. On this basis, Caputo & Degl'Innocenti (1995) have recently speculated about the possible occurrence of metal deficient He burning pulsators. Due to the lack of investigation on the evolutionary scenario concerning similar metal deficient, but not too old, stellar systems, it is obviously interesting to extend to lower metallicities the evolutionary scenario presented in the above referred literature.

This paper will present the results of such an investigations, as performed exploring the evolutionary behavior of stars with $Z = 10^{-5}$, a metallicity value adopted as suitable lower limit for the amount of heavy elements in dwarf spheroidal systems. In section 2 we will discuss the H burning evolution for the given choice on the stellar metallicity. Starting from these results, section 3 will deal with the results concerning He burning phases. A final discussion will close the paper.

2. The H burning phase in metal deficient stars.

In order to extend the theoretical scenario concerning stars with $Z = 10^{-5}$ down to cluster ages of about 1 Gyr, evolutionary tracks already presented in Paper I for the quoted metallicity have been implemented with new tracks for suitable choices of the stellar masses. All the computations have been performed adopting a cosmological abundance of He as given by $Y = 0.23$.

As well known, the modality of He ignition significantly depends on the total mass of the evolving giant. For each given stellar population (i.e., for each assumed value of Y and Z), one may define a critical mass M_{HeF} as the upper mass limits for stars experiencing strong electron degeneracy of the He core during the H shell burning phase and - thus - igniting He through one or more violent He flashes. One finds that evolutionary features of red giant (RG) stars with masses around M_{HeF} change in a remarkable way in a range of only few tenths of solar mass, an occurrence already known as '*Red Giant Branch Transition*' (RGT) (see Sweigart, Greggio & Renzini 1989, hereafter SGR, Sweigart, Greggio & Renzini 1990, Castellani et al. 1992).

The behavior of our Z=10^{-5} models through the transition is shown in figure 1, which shows the dependence of M_c^{tip} (the mass of the He core at the He ignition) and L_{tip} (the star luminosity at the tip of RGB) on the stellar mass. According to Sweigart & Gross (1978) and SGR, the onset of the helium flash has been taken at the model where the contribution of 3α reactions to the energetic reaches $100L_{\odot}$; for structures which quietly ignite helium, the He ignition has been alternatively fixed at the first appearance of a convective core. The sudden variation of L_{tip} around M=$1.5M_{\odot}$ indicates that this stellar mass is near the

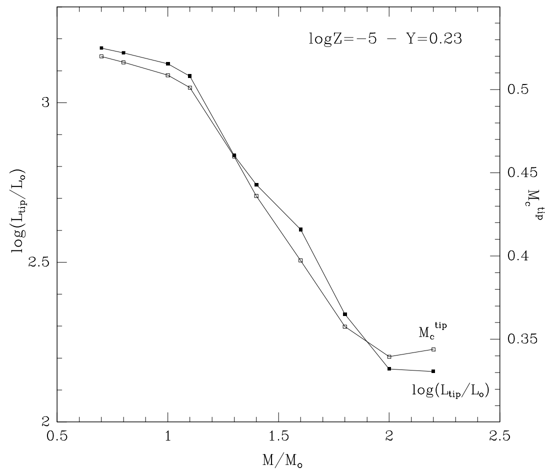

Figure 1. The luminosity of the RGB tip and the mass of the helium core at the helium ignition versus the total star mass when Z=10^{-5}.

transition between low mass stars developing full degenerate Helium cores and more massive structures where electron degeneracy is progressively removed. As in previous investigations, if one defines the critical mass M_{HeF} as the mass of the star having at the He ignition a He core mass equal to the average value between the He core of fully degenerated structures and the absolute minimum in M_c^{tip}, when Z=10^{-5} one finds M_{HeF} of the order of 1.45$M_\odot$. Table 1 reports selected evolutionary parameters for all the computed models, allowing a quantitative inspection of the RGB transition.

Figure 2 compares the amount of extrahelium brought to the surface by the first dredge up with similar data but for the larger metallicities investigated in Paper I. As already discussed in Castellani & Degl'Innocenti (1995), for each given metallicity one finds a stellar mass separating the regime of low mass stars where ΔY increases when the stellar mass is increased from more massive stars with opposite behavior. Such an occurrence as well as the dependence of ΔY on the star metallicity can be easily understood in terms of the discussion given by Castellani & Degl'Innocenti (1995).

Figure 3a shows the dependence of the critical mass M_{HeF} on star metallicity. In this figure, present results have been implemented with similar data given by Cassisi & Castellani (1993) or by SGR for lower or larger metallicities, respectively. The dependence of M_{HeF} on Z has been already discussed (see Cassisi and Castellani 1993) and this discussion will not be repeated here. As a relevant point figure 3b discloses the dependence on the metallicity of the cluster age at the Helium ignition in stars with mass M=M_{HeF}. It appears that when Z=10^{-5} the transition requires ages of the order of about 2.2 Gyr, i.e., a much larger age than for the Z=10^{-4} case. As a consequence, in a dwarf galaxy

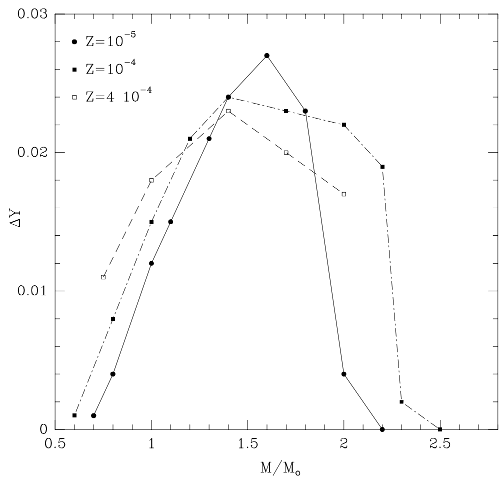

Figure 2. The amount of extra-helium brought to the surface by the first dredge up for all the computed models. For the sake of comparison, the results concerning two different assumptions about the stellar metallicity are reported.

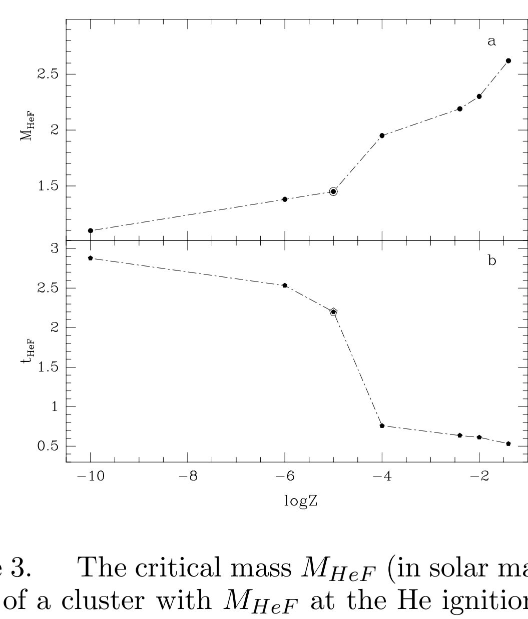

Figure 3. The critical mass M_{HeF} (in solar mass) (a) and the age (in Gyrs) of a cluster with M_{HeF} at the He ignition (b) versus the global amount of heavy elements.

Table 1. Selected evolutionary parameters at the He ignition: 1) the star mass, 2) the stellar luminosity at the tip of the RGB, 3) the mass (in solar unit) of the He core, 4) the amount of extra-helium brought at the surface by the first dredge up and 5) the age (in Gyrs) of the star.

$M/M_{\odot}$	$log(L/L_{\odot})_{tip}$	M_c^{tip}	ΔY	t_{HeF}
1.1	3.083	0.501	0.015	5.04
1.3	2.835	0.460	0.021	2.89
1.4	2.743	0.436	0.024	2.27
1.6	2.603	0.397	0.027	1.47
1.8	2.338	0.358	0.023	1.01
2.0	2.166	0.339	0.004	0.72
2.2	2.158	0.344	0.000	0.53

with star metallicities ranging from Z=10^{-5} to Z=10^{-4} and ages around 1 Gyr, the red giant branch is expected to be populated by the more metal rich stars only. As a result, one finds that the distribution of metallicity of RG cannot taken in all cases as a bona fide indicator of the distribution of star metallicity in 'not-too-old' metal poor systems.

Evolutionary models, as computed for the case Z=10^{-5} allow us to extend toward lower ages the set of isochrones presented in Paper I. This is shown in figure 4 where we report selected isochrones for H burning stellar structures covering cluster ages from 0.8 to 7Gyrs.

3. The evolution along the He burning phase.

Evolutionary data for H burning stars, as given in the previous section, allow to investigate the evolution of stellar structures along the He burning evolutionary phase, following a procedure quite similar to that used in investigating the evolutionary properties of low mass He burning stars in galactic globular clusters. For each assumption concerning the chemical composition and the age of a cluster, one obtains from H-burning evolutionary computations the mass of stars at the He ignition (M_{RG}) and both the He core mass (M_c^{tip}) and the amount of extrahelium ΔY brought at the surface by the first dredge up. When all these quantities are known, Zero Age Horizontal Branch (ZAHB) models can be obtained, computing the sequence of stellar structures, burning helium inside a He core of mass M_c^{tip}, surrounded by an envelope enriched by ΔY, with a global mass fulfilling the condition that $M_{tot} = M_c^{tip} + M_{envelope} \leq M_{RG}$.

However, at variance with the case of old globular cluster stars, the value of M_c^{tip} is now sensitively depending on the value of M_{RG}, i.e. on the cluster age. Since the luminosity of the ZAHB is largely dependent on the mass of the He core, one expects a large dependence of the ZAHB luminosity on the age of the stellar system. This occurrence is shown in figure 5, where ZAHB locations for the various labeled assumptions about the cluster ages are plotted. Table 2 gives selected evolutionary quantities for all the computed ZAHB models.

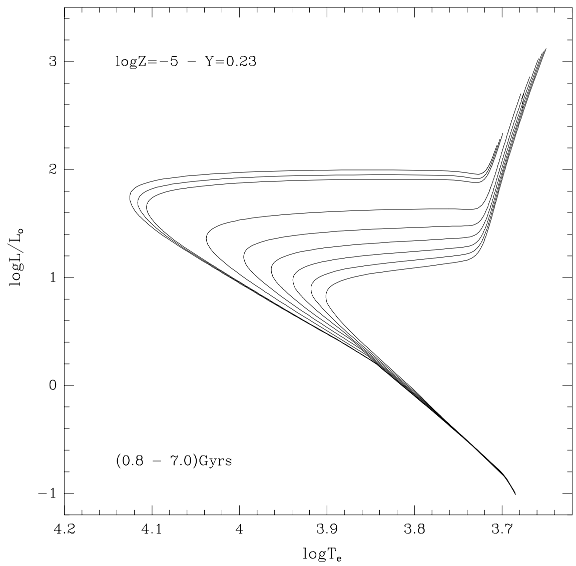

Figure 4. Cluster isochrones for H burning phases and for the labeled range of ages. The interval is 100 Myr for ages lower than 1 Gyr and 1 Gyr for larger ages.

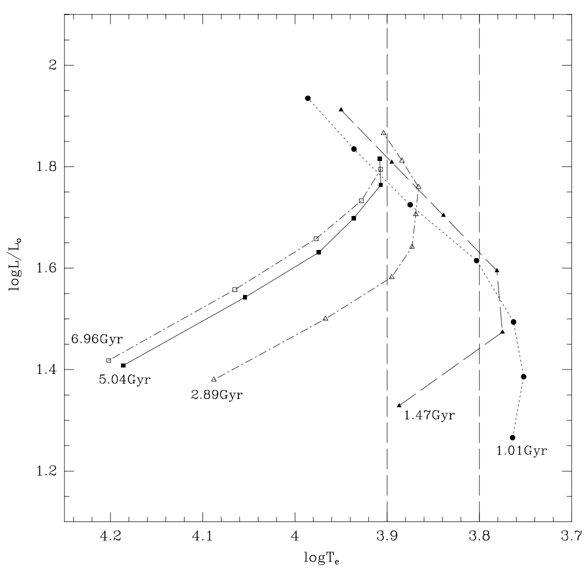

Figure 5. The locus in the HR diagram of ZAHB structures for the various labeled assumptions about the cluster age. The mass of the various models is reported in Table 2.

Table 2. Selected evolutionary parameters for He burning stellar models. The stellar mass, the luminosity and the effective temperature of the ZAHB model and the central He burning lifetime (in $10^6 yrs$) are reported in the order for the various labeled assumptions about the cluster age, i.e., for the given mass of the original progenitor.

$M/M_\odot$	$log(L/L_\odot)_{ZAHB}$	$logTe_{ZAHB}$	$\tau_{He-burn}$	$t_{HeF}(Gyr)$	$M_{pr}/M_\odot$
0.60	1.408	4.186	112	5.04	1.1
0.70	1.543	4.054	103	5.04	1.1
0.80	1.631	3.974	97	5.04	1.1
0.90	1.699	3.936	93	5.04	1.1
1.00	1.764	3.907	90	5.04	1.1
1.10	1.816	3.908	88	5.04	1.1
0.60	1.380	4.088	142	2.89	1.3
0.70	1.500	3.967	130	2.89	1.3
0.80	1.582	3.895	124	2.89	1.3
0.90	1.642	3.873	119	2.89	1.3
1.00	1.706	3.869	114	2.89	1.3
1.10	1.760	3.866	110	2.89	1.3
1.20	1.812	3.884	107	2.89	1.3
1.30	1.866	3.904	104	2.89	1.3
0.60	1.329	3.887	221	1.47	1.6
0.80	1.474	3.775	193	1.47	1.6
1.00	1.595	3.781	173	1.47	1.6
1.20	1.704	3.839	158	1.47	1.6
1.40	1.809	3.895	145	1.47	1.6
1.60	1.912	3.950	132	1.47	1.6
0.60	1.266	3.764	302	1.01	1.8
0.80	1.386	3.752	263	1.01	1.8
1.00	1.494	3.763	233	1.01	1.8
1.20	1.615	3.803	209	1.01	1.8
1.40	1.725	3.875	188	1.01	1.8
1.60	1.835	3.936	170	1.01	1.8
1.80	1.935	3.986	153	1.01	1.8

As early recognized by Caloi, Castellani & Tornambé (1978), inspection of figure 5 reveals that increasing the total mass the effective temperature of a ZAHB model decreases until a minimum temperature is reached, after that the temperature starts increasing with mass. As for the origin of this minimum, one finds that for each given value of M_c^{tip}, increasing the mass of the envelope, the temperature in the H burning shell continuously increases whereas the density decreases. The behavior of the central condition is almost specular, since increasing the stellar mass the density increases and the temperature, slightly, decreases. As a result, the ratio between the luminosity due to H or He burning monotonously increases when the mass of the envelope is increased over the whole explored range of masses. Thus the occurrence of the minimum in temperature cannot be related to the relative efficiency of the burning. The occurrence of this minimum can be much more simply related to the evidence that increasing the stellar mass (i.e. the mass of the envelope), the core and shell-burning regions behave more and more as a central energy source. As a consequence, the more massive ZAHB models shift towards larger effective temperature approaching a MS-like location.

Figs. 6 (a to d) show the evolutionary paths in the HR diagram of the models in figure 5 during the phase of central and shell He burning. As already recognized for larger metallicity by Caputo & Degl'Innocenti (1995), one finds that the allowed range in magnitude of He burning red giants increases when the cluster age decreases. Thus the observed range of magnitudes can be used to put an upper limit to the age of stellar systems even in the $Z = 10^{-5}$ case. As for the post-HB evolution, all computed models have envelopes massive enough to make them approach their Hayashi tracks during the double shell burning phase.

In both Figures 5 and 6 (a to d) we report the temptative location of the region for pulsational instability, allowing a discussion of the possible occurrence of variable stars in stellar populations with Z=10^{-5}. As well known, old very metal poor systems cannot produce ZAHB pulsators since the ZAHB locations are in all cases hotter than the instability strip. According to Cassisi et al. (1995), this is the case for metallicities log$Z \leq -5$ and ages larger than about 7 Gyrs. As expected, now one finds that, for ages smaller than - about - 5.1 Gyrs metal deficient clusters start allowing ZAHB pulsators. Decreasing the cluster age, the range of masses in the instability strip increases. For ages of about 2.8-2.9 Gyrs one finds that all ZAHB models more massive than $0.8M_{\odot}$ are inside the instability strip. In similar clusters one should expect an anomalous clump of He burning pulsating stars. However, a detailed discussion on the pulsational scenario concerning similar metal poor variables is beyond the aim of the present work. For a deeper investigation on the pulsational properties of these metal poor stars, we will address to a forthcoming paper (Bono et al. 1996).

Figures 7 (a to d) and 8 (a to d) show the time evolution of luminosity and effective temperature of the models in figures 6 (a to d) during both central and shell He burning phases. Without enter into a detailed discussion, let us only notice the progressive increase of the He central burning lifetimes when the cluster age is decreased. This is the expected result of the corresponding decrease of the mass of the He-core in ZAHB models. As a consequence, one expects an

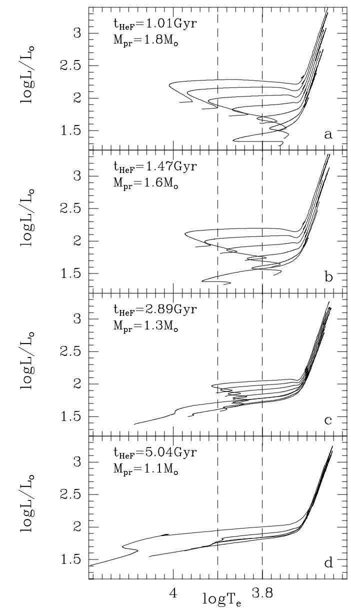

Figure 6. The evolutionary path in the HR diagram of He burning models for the labeled assumptions about the cluster age. The initial mass of the progenitor (M_{pr}) is also reported. The vertical dashed lines sketch the temptative location of the strip for pulsational instability.

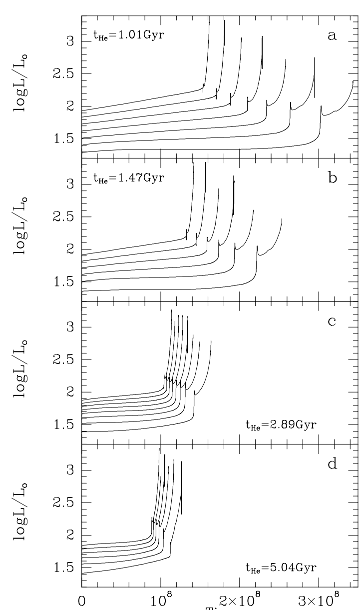

Figure 7. The behavior with the time of the luminosity during the central and shell He burning phases for the labeled assumptions concerning the cluster ages.

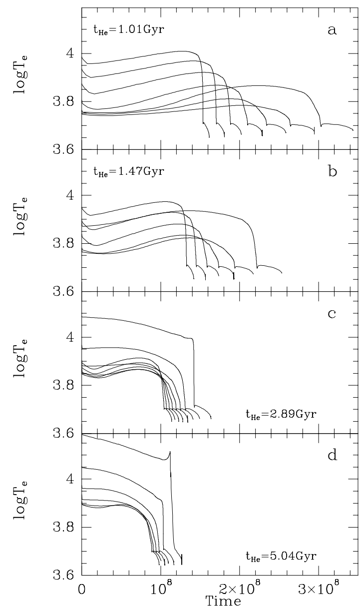

Figure 8. The behavior with the time of the effective temperature for all models computed in the present work during the central and shell He burning phases for the labeled assumptions concerning the cluster ages.

increasing evidence for He-burning giants which will eventually dominate the cluster giant population.

4. Conclusions.

This paper investigates the evolutionary properties of relatively massive, metal deficient stellar structures. The first part of the investigation has been devoted to H burning stars, presenting selected isochrones for ages in the range 800 Myr - 7 Gyr, increasing the range of ages covered by previous investigations.

Selected sets of HB models have been computed under different assumptions about the ages of the stellar system. We confirm the results already given for larger stellar metallicities about the possible, and sometime probable, occurrence of anomalous, overluminous variable stars, in relatively young, metal deficient system.

Both evolutionary tracks and isochrones are available by electronic mail upon request to cassisi@astrte.te.astro.it.

Acknowledgments. We thank F. Caputo for helpful discussions and for suggesting the need for such a completion of the current evolutionary scenario. S.C. thanks also O. Straniero and A. Tornambé for useful and stimulating discussions.

References

Bond H.E. 1970, ApJS22, 117

Bono G., Caputo F., Cassisi S., Piersimoni A.M. & Santolamazza P. 1996, *in preparation*

Caloi V., Castellani V. & Tornambé A. 1978, A&AS33,169

Caputo F. & Degl'Innocenti S. 1995, A&A298,833

Cassisi S. & Castellani V. 1993, ApJS88,509

Cassisi S., Castellani V. & Tornambé A. 1995, ApJ*in press*

Castellani V., Chieffi A. & Straniero O. 1992, ApJS78,517

Castellani V. & Degl'Innocenti S. 1995, A&A298, 827

Molaro P. & Castelli F. 1990, A&A228, 426

Nemec J.M., Nemec A.F.L. & Lutz T.E. 1994, AJ108, 222

Primas F., Molaro P., Castelli F. 1994, A&A290 ,885

Sneden C., Preston G.W., McWilliam A., Searle L. 1994, ApJ431, L27

Sweigart A., Greggio L., & Renzini A. 1989, ApJS69, 911 (SGR)

———-. 1990, ApJ364, 527

Sweigart A. & Gross P. 1978, ApJS36, 405